Feedback Control in LS-DYNA and Application for Modeling Muscles Responses of Car Occupants

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What is Feedback Control?

• Information about the state of the controlled system is fed back and used to generate the control signal

\[ u(t) = k_p \cdot e(t) \]

• Historical example
  – The centrifugal governor (Watt & Boulton 1788)
  – Proportional control

• Modern applications
  – Vehicle Stability Control Functions
  – In Biological Systems
Driving Forces for Feedback Control in Human Body Models

- Mathematical HBM:s for development of Automotive Safety systems

- Novel safety systems integrate pre-crash and crash technologies

- Creates a requirement for inclusion of postural muscle responses in HBM
  - The human postural control system is a feedback control system!
Control Strategy in Active HBM

- First coded in solution control subroutine uctrl1
- Andersson (2013) identified missing functionality
- PID controller

\[ e(t) = r(t) - y(t) \]
\[ u(t) = k_p \cdot e(t) + k_i \cdot \int_0^t e(\tau) d\tau + k_d \cdot \frac{de(t)}{dt} \]
New *DEFINE_CURVE functionality

- AHBM uses *MAT_MUSCLE (156)
  - Force scaled by activation level (0-100%)
  - Constant or defined by load curve, feedback possible using *DEFINE_CURVE_FUNCTION

- *DEFINE_CURVE_FUNCTION: DELAY
- *DEFINE_CURVE_FUNCTION: PID_CTL
*DEFINE_CURVE_FUNCTION:DELAY

*DEFINE_CURVE

$#    lcid sidr sfa sfo offa offo dattyp
1     0  1.000000  1.000000  0.000  0.000         0
$#
0.000  0.00000000000
100.000  0.00000000000
100.0001  1.00000000000
1000.000000  1.00000000000

*DEFINE_CURVE_FUNCTION

$#    lcid sidr sfa sfo offa offo dattyp
2     0  1.000000  1.000000  0.000  0.000         0
$#
function
DELAY (1,20.0,0.0)

Syntax:
DELAY (LCID, DELAY, INIT. VAL)
*DEFINE_CURVE_FUNCTION: PIDCTL

**DEFINE_CURVE**

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$e(t) = r(t) - y(t)$

$u(t) = k_p \cdot e(t) + k_i \cdot \int_0^t e(\tau)d\tau + k_d \cdot \frac{de(t)}{dt}$

**Example:**

\[ e(t) = \frac{x(t) - \frac{\partial^2}{\partial t^2}x(t)}{15} \]
PIDCTL Example

Legend
- A LC1 Reference position
- B P-Control
- C PD-Control
- D PID-Control
- E PID-control with 0.14 ms delay

- X-position (mm)
- Time (ms)
Application in HBM

Autonomous Braking

Driver Braking
Conclusions

• Feedback control of mechanical systems has many engineering applications
  — New curve function **PIDCTL** allows for PID control in LS-DYNA
  — New curve function **DELAY** enables modeling of transport delays in feedback systems
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References

Andersson S (2013) *Active Muscle Control in Human Body Model Simulations: Implementation of a feedback control algorithm with standard keywords in LS-DYNA*. MSc Thesis; Division of Vehicle Safety, Department of Applied Mechanics, Chalmers University of Technology; Gothenburg, Sweden